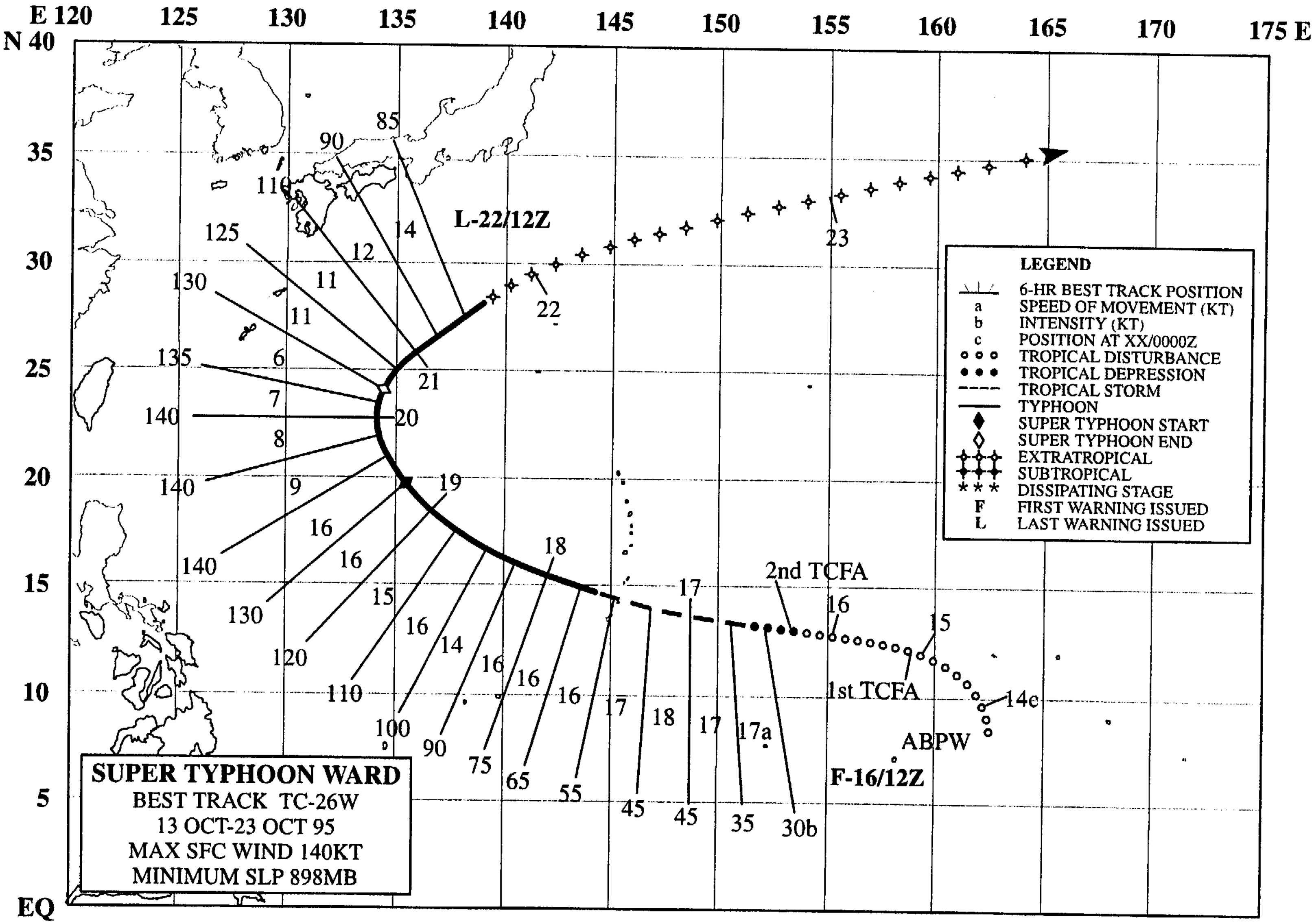

SUPER TYPHOON WARD
BEST TRACK TC-26W
13 OCT-23 OCT 95
MAX SFC WIND 140KT
MINIMUM SLP 898MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
125
130
135
140
145
150
155
160
165
170
175 E
N 40
35
30
25
20
15
10
5
EQ
L-22/12Z
F-16/12Z
2nd TCFA
1st TCFA
ABPW

SUPER TYPHOON WARD (26W)

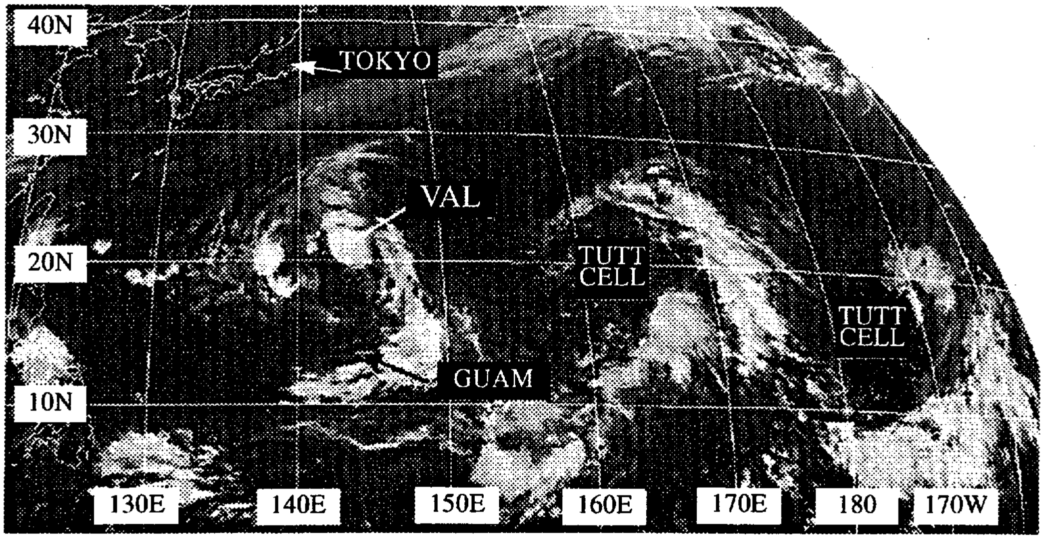

Figure 3-26-1 A chain of three atmospheric vortices with similar satellite signatures is spread across the tropics of the western Pacific: a monsoon gyre with an embedded tropical cyclone — Val (25W), and two TUTT cells centered at the indicated locations (100033Z October infrared GMS imagery).

I. HIGHLIGHTS

The fourth of five super typhoons during 1995, Ward formed as a small tropical cyclone east of Guam. Guam's NEXRAD provided a detailed look at the structure of this small tropical cyclone as it was intensifying and passing through the southern Mariana Islands. Ward's first visible eye was very small; it was later replaced by an average sized eye.

II. TRACK AND INTENSITY

The tropical disturbance that became Ward had it origins in the Marshall Islands where a nearly stationary area of deep convection associated with a chain of TUTT cells was present as early as 10 October (Figure 3-26-1). This area of convection remained poorly organized for the next few days, and was comprised of mesoscale convective systems that grew and decayed. On 14 October, this area of deep convection — located to the south of a well-defined TUTT cell — became more organized (e.g., a cyclonically curved band composed of mesoscale convective systems and anticyclonically curved streamers of outflow cirrus), prompting its first mention on the 131800Z October Significant Tropical Weather Advisory.

While moving westward in tandem with the TUTT cell to its north, the deep convection in this tropical disturbance began to consolidate around a well defined low-level circulation center. This prompted the JTWC to issue a Tropical Cyclone Formation Alert (TCFA) at 150130Z October. At 152330Z, the TCFA was canceled when amounts of deep convection near the center diminished. A second TCFA was issued soon thereafter at 160830Z when persistent deep convection once again consolidated near the low-level circulation center. The JTWC issued the first warning on Tropical Depression 26W valid at 161200Z when it became apparent in satellite imagery that the system was rapidly becoming better organized. By the morning of 17 October, satellite imagery indicated a significant improvement in the organization of TD 26W, and it was upgraded to Tropical Storm Ward at 170000Z. Moving rather quickly at 17 kt (32 km/hr) toward the west, Ward passed between the islands of Rota and Saipan, or about 70 nm (130 km) to the north of Guam, during the night of 17 October. At 171800Z, Ward was upgraded to a typhoon based upon a maximum inbound velocity of 81 kt (42 m/sec) at 7,000 ft above sea level as depicted by Guam's NEXRAD, and also as corroborated by satellite intensity estimates.

After becoming a typhoon, Ward began to track on a more northwestward direction. Moving towards a "break" (i.e., a col) along the axis of the mid-tropospheric subtropical ridge axis, Ward slowed, turned toward the north and reached its point of recurvature at 200000Z. While approaching its point of recurvature, Ward also intensified, and attained its peak intensity of 140 kt (72 m/sec) at 191200Z (Figure 3-26-2). After passing through the ridge axis, Ward turned sharply toward the northeast, accelerated, and

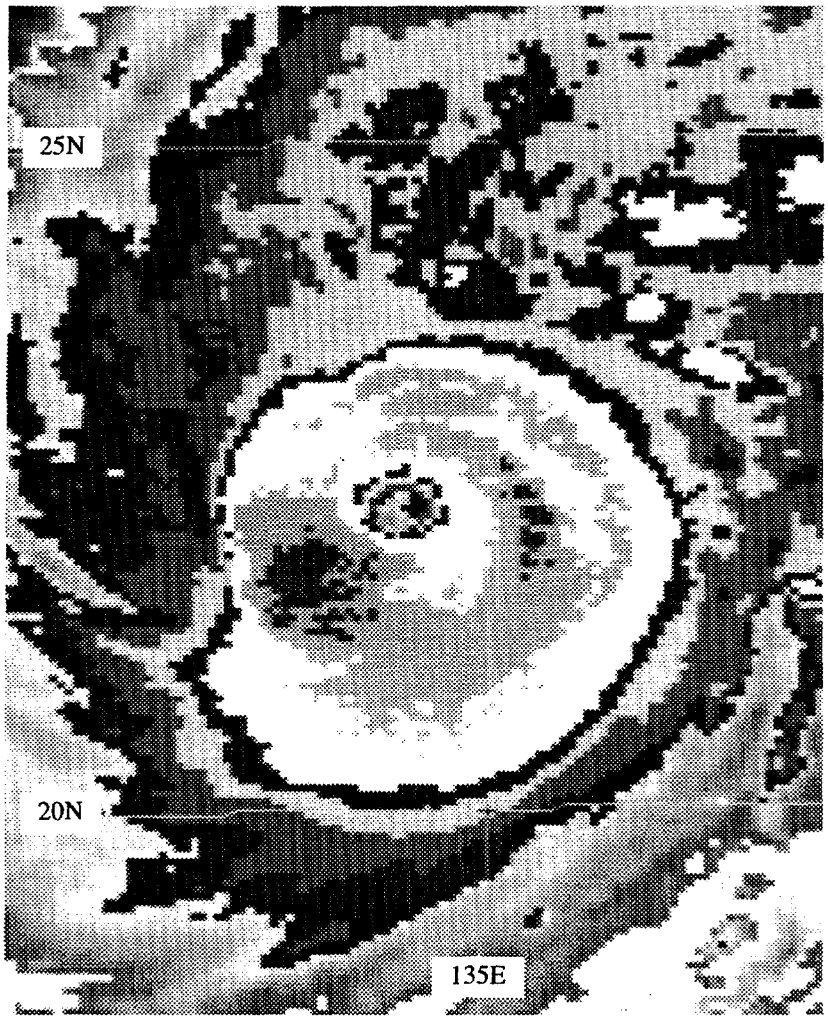

Figure 3-26-2 Ward at peak intensity of 140 kt (72 m/sec) (191931Z October enhanced infrared GMS imagery).

began to weaken as the vertical wind shear in the westerly wind flow north of the subtropical ridge sheared the system. At 220600Z, Ward was downgraded to a tropical storm as the low-level circulation became fully exposed to the southwest of its extensive shield of multi-layered middle and high cloud — a typical appearance of a tropical cyclone undergoing extratropical transition (Figure 3-26-3). Based upon the expected completion of its extratropical transition, the final warning was issued at 221200Z.

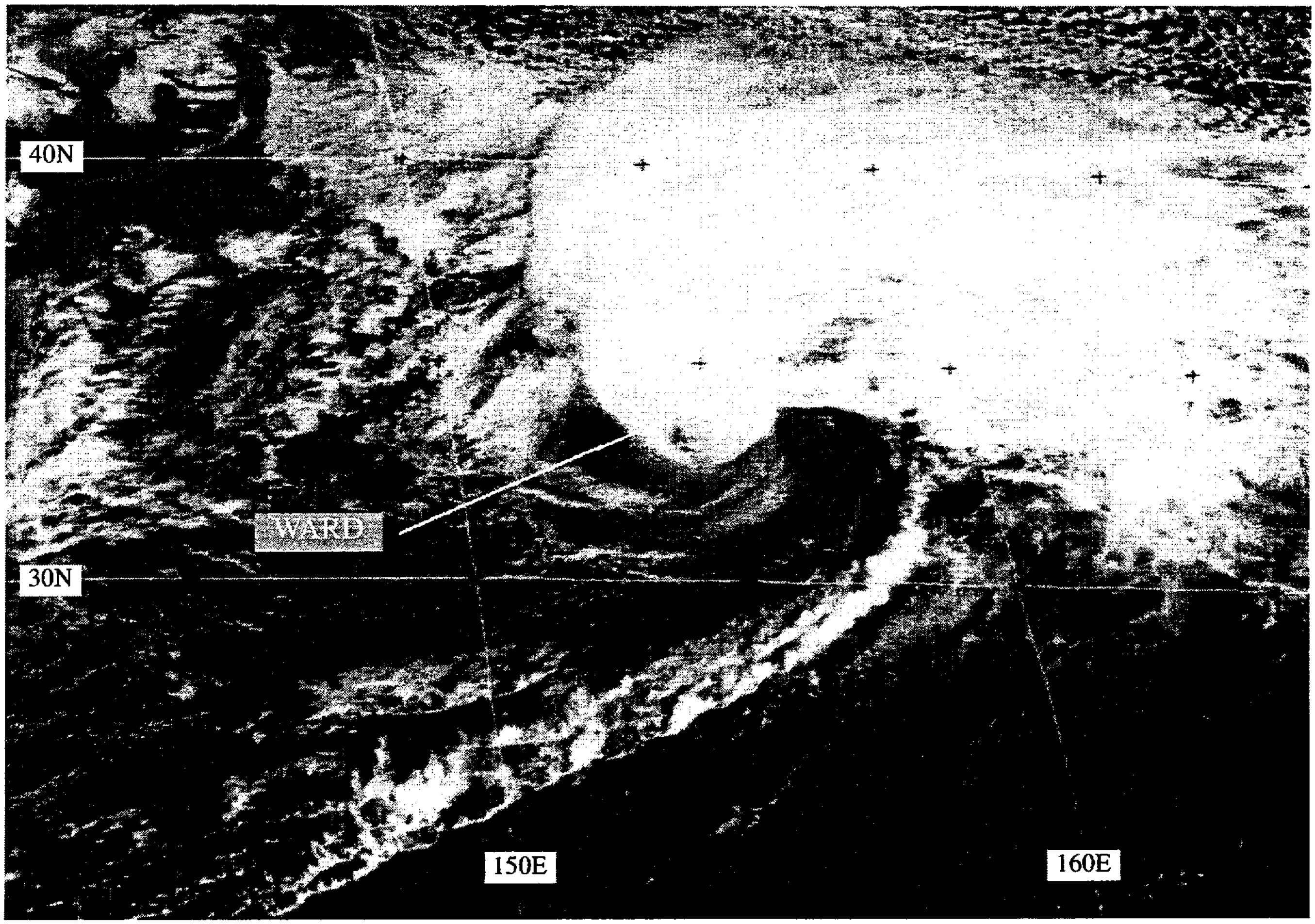

Figure 3-26-3 Ward's extratropical transition is nearly complete (222331Z October visible GMS imagery).

III. DISCUSSION

a. *A NEXRAD view of the early development of Ward*

During the night of 17 October, Ward passed between the islands of Rota and Saipan, or about 70 nm (130 km) to the north of Guam. This placed the small circulation of the intensifying Ward well within the range of Guam's NEXRAD. While within the 124-nm range of the NEXRAD Doppler capability, Ward moved toward the west-northwest at an average translational speed of 17 kt (32 km/hr) and intensified from 45 to 65 kt (23 to 33 m/sec). One aspect of Ward's structure that was well-depicted by the NEXRAD was the nature of the wind asymmetry. The wind asymmetry between the north side and the south side of Ward appeared to be primarily a result of Ward's translation speed. The effect of the translation was almost fully represented. At a translation speed of 17 kt, one would expect the difference in the wind speed between the north side and the south side of Ward to be twice the speed of translation, or approximately 35 kt. As Ward came within the Doppler range, about 120 nm (220 km) to the east-northeast of Guam, a maximum inbound wind of 50 kt (26 m/sec) was present on the north side at the lowest beam altitude of 16,000 ft. On the south side of Ward, the maximum outbound wind was 17 kt (9 m/sec) (also at 16,000 ft). The differential between the inbound and outbound wind was thus 33 kt, or very nearly what would be expected from a full accounting of the speed of translation. Later, as Ward moved due north of the NEXRAD (and thereby placing the asymmetry introduced by the speed of translation perpendicular to the radar), the inbound and outbound velocities became nearly equal at about 65 kt each way, and both at the lowest beam elevation of 7,000 ft.

This brings us to another structural characteristic of Ward's wind field as revealed by the NEXRAD: the maximum wind speed, whether inbound or outbound, always occurred at the lowest possible beam elevation. In this case, the lowest altitude of beam penetration was 7,000 ft when Ward was at its closest point of approach. That the highest winds in a TC should be at a low level is not a surprising finding, however, in some other TCs that have come even closer to Guam (e.g., Eli (04W) and Verne (1994)), the maximum winds near the center have been observed to occur at elevations as low as 2,000 feet; and again nearly always at the lowest possible viewing altitude of the NEXRAD. Such findings bring into question the conventional tactic of reducing aircraft reconnaissance flight-level wind speed (usually near 10,000 ft) by 80% to estimate the surface wind speed.

Ward was a small-sized tropical cyclone as it passed to the north of Guam. When due north of Guam, the distance between the maximum inbound and outbound winds was only 12 nm (22 km) at 7,000 ft. The diameter of gale-force winds was approximately 40 nm (75 km) at 7,000 ft. The speed of the westerly winds on Guam when Ward passed only 70 nm (130 km) to the north was only 10 kt (5 m/sec). The subsequent growth in size and the large increase of the intensity of this small vortex was a remarkable structural change.

Some additional general structural characteristics of tropical cyclones passing within the range of Guam's NEXRAD are: (1) the maximum wind speed is found at the lowest beam elevation in the most highly reflective and deepest convection, (2) over time scales on the order of tens of minutes, the wind speeds rise and fall as deep convective elements grow and decay, and (3) when deep convection grows in the eye wall, wind speeds increase throughout the depth of the troposphere and become more nearly constant with height (i.e., the deep convection appears to be accelerating the wind velocity, and also to be transporting the momentum to higher altitudes).

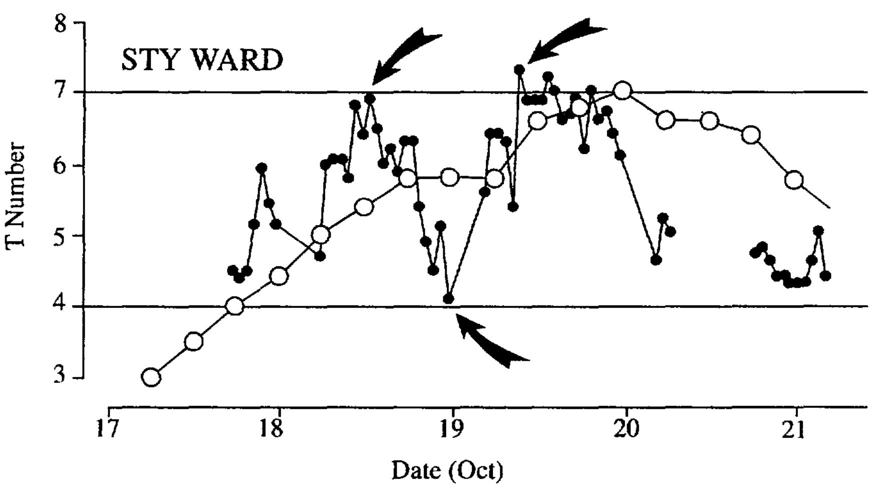

Figure 3-26-4 A time series of Ward's hourly "Digital" Dvorak (DD) intensity estimates (black dots). Also shown is the warning intensity (converted to a T number) (open circles). Arrows indicate two peaks and an intervening minimum in the DD time series.

b. *Evidence of two intensity peaks related to eye structure*

Ward was another of the year's tropical cyclones for which hourly values of the Digital Dvorak (DD) numbers (Figure 3-26-4) were tabulated during much of its life (see Oscar's (17W) summary for a description of the DD algorithm installed on the JTWC's MIDDAS satellite image processing equipment). The time series of Ward's DD (Figure 3-26-4) indicates two peaks of intensity near T 7.0 (equivalent to 140 kt): one near 181200Z and the other 24 hours later at 191200Z. Between these two peaks, the DD indicated that the intensity fell as low as T 4.0 (minimal typhoon intensity) at about 190000Z.

These two intensity peaks are closely related to the evolution of Ward's eye. After first becoming a typhoon, Ward's eye was extremely small (as seen by NEXRAD and later as it appeared on visible satellite imagery). After attaining its first intensity peak at 181200Z with a very small eye (Figure 3-26-5), the eye clouded over (resulting in lower intensity estimates) and then reappeared at a larger size when it attained its second peak intensity at 191200Z (Figure 3-26-2).

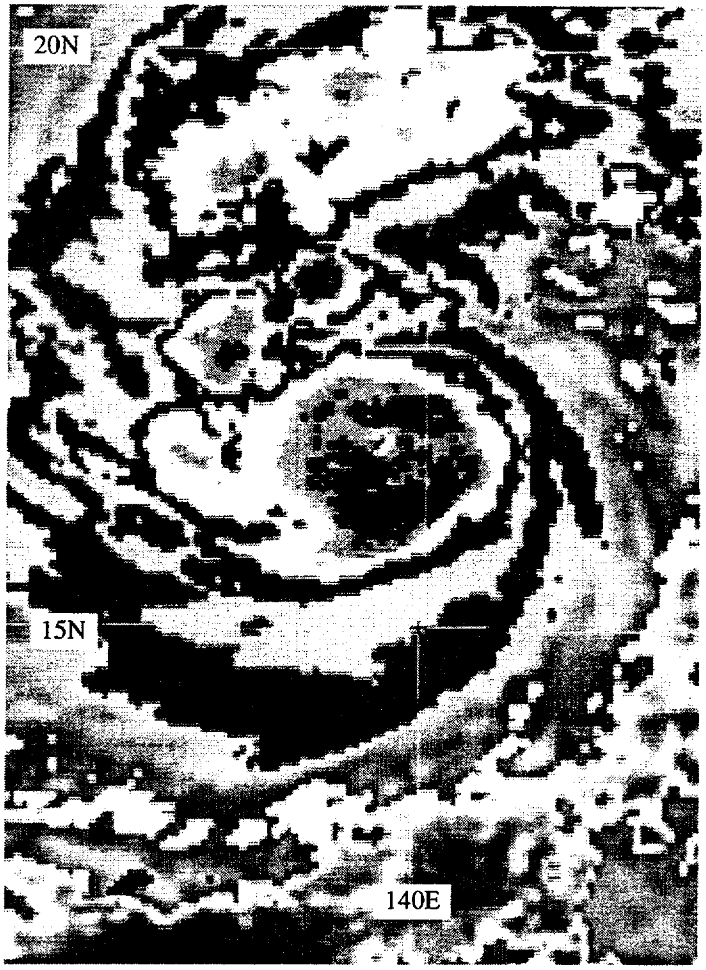

Figure 3-26-5 Ward possesses a very small eye at the time of the first peak on the DD time series (181031Z October enhanced infrared GMS imagery).

Similar to the case with Ryan (19W), the warning intensity and the final best-track intensity do not reflect the first peak of the DD (i.e., DD = 140 kt; final best-track = 100 kt). As the DD rose to its second peak, the warning and final best-track intensity rose to match it (i.e., DD = 140 kt; final best-track intensity = 140 kt). Once again, the DD has revealed extremely large and rapid fluctuations of intensity that were not reflected in the warning intensity or the final best-track intensity. In the absence of ground truth measurements, it is not possible to know in fine detail how Ward's intensity changed. In the case of Ward, there is a clear reason for the rapid changes in the DD intensity: the changes in Ward's eye characteristics. If the DD truly represented Ward's intensity, there are two sobering implications: (1) an extremely rapid increase of intensity occurred that was not reflected in the warning, and (2) the best-track data base, having had these rapid fluctuations removed, can not be used to study the processes governing what may prove to be real intensity fluctuations of the magnitude indicated by the DD.

IV. IMPACT

As Ward passed through the Mariana Islands it affected the islands of Rota, Tinian and Saipan. Heavy rain caused minor flooding on several Saipan streets. On Tinian, gusty winds and heavy rains caused a loss of electrical power to half of the island.